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The Use of Brine Shrimp *Artemia* in Biological Management of Solar Saltworks

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ABSTRACT

In recent years, there has been a growing awareness of the hydrobiological aspects of the solar salt production process. Saltworks are man-managed artificial ecosystems that are highly vulnerable to biological disturbances, including uncontrolled proliferation of microalgae resulting in a reduced evaporation and contamination of the salt with gypsum and insoluble organic materials.

Optimal production of solar salt; both in terms of quality and quantity, requires a well-established balance between the primary and secondary producers, with brine shrimp *Artemia* grazing on phytoplankton constituting the major interaction. In this paper, we discuss the beneficial role of *Artemia* in balancing the hydrobiological activity of the salt pond system and highlight some of the critical aspects essential to proper management of *Artemia*, including selection and controlled introduction of the most suitable strain of *Artemia*.

Furthermore, the possibilities for establishing a vertically integrated aquaculture industry brought about by the opportunities for harvesting of *Artemia* cysts and biomass as valuable by-products of the solar salt operation will be discussed. Results of experiences gained in different projects around the world will be presented.

THE NATURAL OCCURRENCE OF *ARTEMIA*

The brine shrimp *Artemia* is a small crustacean which is widely distributed on the five continents in hypersaline biotopes including salt lakes (coastal or inland waters rich in chloride, sulphate or carbonate) and especially in coastal salinas (man-made and/or managed solar saltworks). Detailed reviews can be found in Persoone and Sorgeloos (1980) and Sorgeloos et al. (1986). The very specific and large range of ecological characteristics of these *Artemia* habitats have resulted in the evolution of many geographical strains. At present over 350 different geographical strains are known (Vanhaecke et al., 1987)

In saltworks *Artemia* is found in the evaporation ponds only at intermediate salinity levels from about 100 ppt, the upper tolerance level of predators, to about 200–250 ppt, when food becomes limiting, and the *Artemia* need more energy for osmoregulation or when the water becomes more toxic in ionic composition as a result of selective crystallisation of salts (see schematic outline in Fig. 1). At high salinities, depending on the local strain as well as the hydrobiological conditions in the ponds (e.g. water retention time, water depth, pond productivity) cysts of *Artemia* (see Fig. 2) are produced seasonally or year-round. They float, tend to be driven by the wind, and often accumulate on the shores of the evaporation ponds.

HARVESTING OF NATURAL *ARTEMIA* HABITATS

Recent developments in aquaculture production of fish and shrimp have resulted in increased demands for *Artemia* as a valuable source of live feed. The present world market of *Artemia* cysts for use in aquaculture is estimated at over 700 t/year. Although the large part of this cyst market is currently supplied by harvests from one single location, i.e. the Great Salt Lake, Utah, USA, there is a steadily-growing interest in the commercial harvesting of other *Artemia* biotopes which is brought about by local import restrictions and/or the increasing demand for *Artemia* products. The quality of the *Artemia* produced differs from strain to

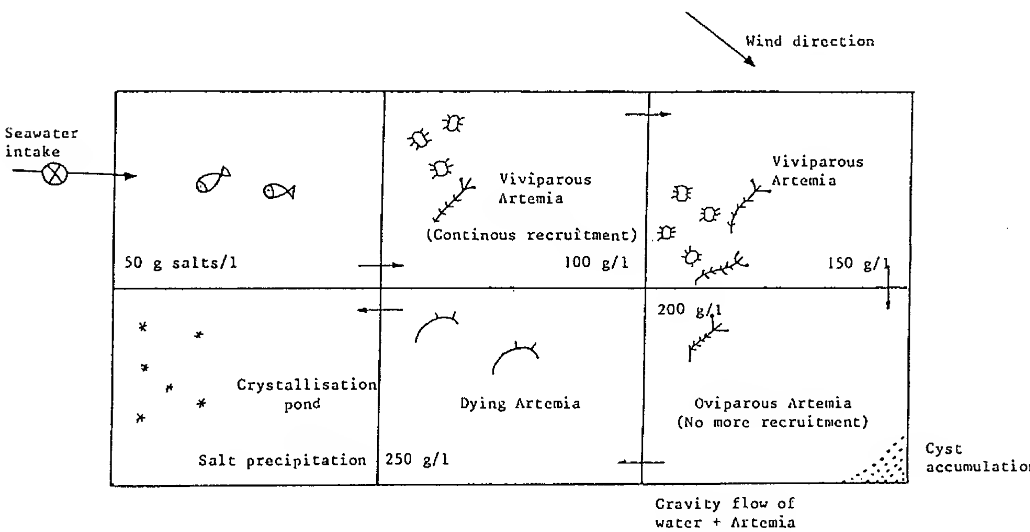

Fig. 1. Schematic diagram of solar salt operation with natural occurrence of *Artemia* (from Sorgeloos et al., 1986).

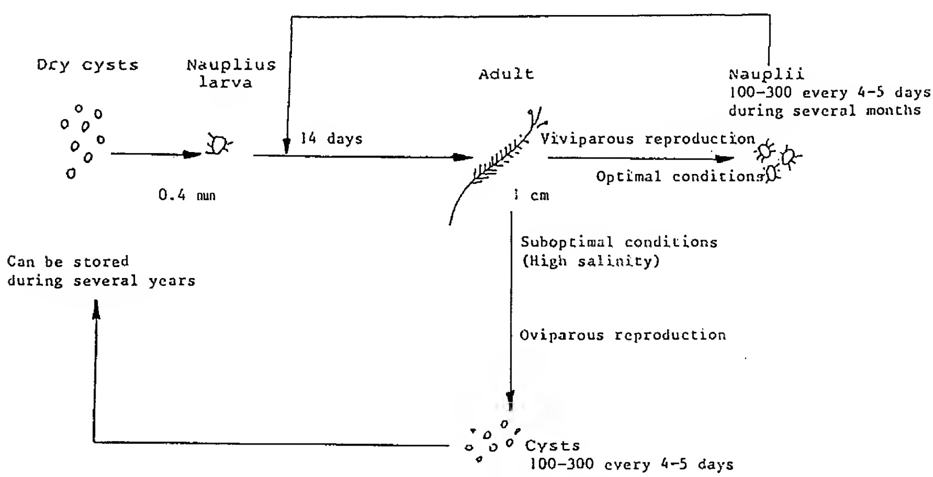

Fig. 2. Schematic diagram of *Artemia* life cycle (from Sorgeloos et al., 1986).

strain and from location to location as a result of genotypical and phenotypical variations (for reviews see Leger et al., 1986, 1987a). It largely reflects the food conditions of the local habitat; adults as well as cysts may be contaminated with high levels of heavy metals, and/or may be deficient in fatty acids essential for marine predators; furthermore, particular strains in specific habitats may produce cysts with unusually low caloric content, e.g. the "sulphate strain" in Chaplin Lake, Canada (Vanhaecke et al., 1983). In this regard it is imperative to determine the nutritional quality of the adult *Artemia* and/or its cysts for specific aquaculture purposes prior to consider commercial use of natural *Artemia* biotopes.

Techniques for cyst/biomass harvesting and treatment are outlined by Sorgeloos et al. (1986). Maxi-

mum sustainable yields of cysts and biomass are influenced by the population dynamics of the local *Artemia* population. The recruitment rate of the population may be high in ponds where the dominant reproduction mode is ovoviviparity, and low in cyst-production ponds. In the low salinity ponds it may be influenced by the role of cysts as inoculum, either after the winter or throughout the year. Furthermore, predation by water birds needs also to be taken into consideration. The determination of maximal harvesting rates is complicated by the heterogenous distribution of the *Artemia*, which makes accurate sampling and consequently precise population estimates very difficult (for more details, see Wear and Haslett, 1987 a,b). Natural recruitment can eventually be increased by introduction of a more productive strain. Fertilization of the *Artemia* ponds can also result in increased production potentials.

In most *Artemia* habitats population densities are very low as a result of food limitation due to low nutrient contents of the intake waters. Some solar saltworks, especially those located in highly eutrophicated areas have, however, a very high productivity, e.g. Leslie saltworks in the San Francisco Bay, California, USA, and the solar saltworks along the Bohai Bay in P.R. China. In the latter area harvesting of cysts and especially biomass, used in local hatcheries and grow-out of white shrimps, has become a considerable industry employing several hundreds of people (Tackaert and Sorgeloos, 1992).

BENEFICIAL ROLE OF *ARTEMIA* IN SOLAR SALTWORKS

Since early times, man has developed systems to concentrate seawater and to harvest sodium chloride as a basic need for his nutrition and health. Over the centuries hundreds and thousands of hectares of salt pans have been constructed, all over the world, in tropical and sub-tropical belts, for so-called solar salt making. The annual production presently amounts to about 200 Mt/year. Less than 10% is used for human consumption, the bulk being consumed by chemical industries (e.g. the chlorine-alkali industries). Seawater contains salts of almost every chemical element including gold in at least trace amounts. Solar salt is normally produced by pumping seawater from one evaporation pond into another, allowing carbonates and gypsum to precipitate, and finally draining NaCl-saturated brine or "pickle" (just before the so-called "salting point" is reached) into crystallizer ponds where sodium chloride precipitates. Before all the NaCl has crystallized out, the mother liquor, now called bittern, has to be drained off to reduce contamination of the sodium chloride with bromides and other salts that begin to precipitate at these elevated salinities. The technique of solar salt production thus involves fractional crystallization of the salts in different ponds to obtain sodium chloride in the purest form possible, e.g. up to 99.7% on a dry-weight basis.

The hydrobiological activity in a solar-salt operation largely determines the quality and quantity of salt produced (Davis, 1978, 1980; Sorgeloos, 1983). In many sites the natural conditions ensure a maximal salt production (e.g. in France, Brazil and South Africa); in other locations, however, proper biological management is needed (e.g. in P.R. China, India, Italy, Australia, Bahamas and Venezuela). Algal blooms, induced by natural availability of organic and inorganic nutrients, are generally beneficial since they ensure increased solar heat absorption, resulting in faster evaporation and increased yields of salt. However, if they are not metabolized in time, algal excretion and decomposition products, such as dissolved carbohydrates, act as chemical traps and consequently prevent early precipitation of gypsum which will contaminate the sodium chloride in the crystallizers and reduces salt quality. Furthermore, such organic impurities as algal agglomerations, which turn black on oxidation, may contaminate the salt and reduce the size of the crystals and hence the salt quality. In the worst situations, high water viscosities may completely inhibit salt crystal formation and precipitation. The presence of the brine shrimp *Artemia* in sufficient numbers is essential not only for controlling algal blooms (Davis, 1980), but also for providing essential nutrients from *Artemia* metabolites and/or decaying animals as suitable substrates for the development of *Halobacterium* in the crystallisation ponds (Jones et al., 1981). High concentrations of red halophilic bacteria promote heat absorption, thereby accelerating evaporation, and reduce concentrations of dissolved organics. Lower viscosity levels promote the formation of larger salt crystals, and thereby improve salt quality (Sorgeloos, 1983; Haxby and Tackaert, 1987). In many salt operations natural recruitment of *Artemia* from cysts dispersed by wind and water birds assures the presence and development of sufficient numbers of brine shrimp for optimal salt operation. In some situations, however, the salt producer should not rely on this opportunistic dispersion of *Artemia*. In saltworks with short water-retention times in their evaporation ponds, a rapid dilution may wash away the *Artemia* population; a hurricane or season of exceptionally heavy rainfall may eliminate or so reduce the local population that it cannot effectively cope with the algae blooms. Some salt-

works may be completely isolated from natural sources of *Artemia* dispersion. In such cases salt producers should optimize the hydrobiological activity in the evaporation ponds through a controlled introduction of brine shrimp. Situations have also been observed where the local *Artemia* population has a poor productivity and remains too small to control the algae and ensure an optimal hydrobiological activity for the salt production. The introduction of a foreign strain, better adapted to the prevailing conditions or with better production characteristics, may improve conditions for production of high quality salt. It is not possible to formulate a general strategy with regard to *Artemia* introductions in solar-salt operations. Each situation needs to be analyzed for specific requirements, with regard to selection of a suitable *Artemia* strain. The quality and quantity of *Artemia* to be introduced must be determined in consideration of the water retention times in evaporation reservoirs, food concentrations, water temperatures, etc. (Sorgeloos et al., 1986).

Proper *Artemia* management should lead not only to improved salt production outputs but also provide opportunities for the harvesting of the valuable by-product *Artemia*, as cysts and biomass.

INTRODUCTION OF *ARTEMIA*

Although *Artemia* is clearly cosmopolitan, a closer look at the regional level reveals that its distribution is discontinuous. *Artemia* does not occur in every existing body of seawater. Brine shrimps cannot migrate from one saline biotope to another via the sea, because they lack anatomical defences against predation by such carnivorous aquatic organisms as larger crustaceans and fish.

The *Artemia* found in several saltworks have probably been accidentally introduced by man. Following an old custom, some salt farmers seeded new saltpans with salt, often containing *Artemia* cysts, from an operational saltwork. All *Artemia* populations in Australia were probably originally introduced by man and now compete, at least in low salinity ponds, with the endemic brine shrimp *Parartemia* spp. (Geddes and Williams, 1987). The absence of a migration route of water birds probably explains why along the northeast coast of Brazil the very large salinas (several 10,000 ha in total area) contained no brine shrimp until *Artemia franciscana* was introduced in 1977 by man in just one saltern in Macau. A few years later it had already been dispersed by local water fowl from Macau to most of the saltworks of north-east Brazil, over a distance of more than 1,000 km (Camara and De Castro, 1983; Camara and De Medeiros Rocha, 1987).

Controlled introduction of *Artemia* by man into suitable biotopes not only provides interesting opportunities for aquaculture production but is also an interesting tool to balance the hydrobiological activity of those salt farms where *Artemia* is absent or too few to effectively cope with algal blooms. However, much caution is needed if one is to preserve the genetic diversity of indigenous brine shrimp populations, especially on the Australian continent, where several endemic species might be endangered by the presence of *Artemia* (see Geddes, 1980, 1981; Geddes and Williams, 1987). On other continents, detailed ecological analyses as well as collection and storage of viable cysts should precede any such new introductions.

Commercial considerations might eventually justify new *Artemia* introductions in solar salt operations where the salt production, quality and quantity, may be impaired by the absence or poor performance of local strains of *Artemia* (e.g. in India, Italy, Venezuela, Bahamas). Various so-called natural or indigenous *Artemia* populations may be ill-adapted to their environment because their local habitat has been modified by man in order to accommodate or improve salt production, resulting in new (sub-optimal) ecological conditions, e.g. in the deep Lago Salpi near Margherita di Savoia in Italy, which was converted into shallow evaporation ponds in which water temperatures in the summer rise above 30°C, lethal temperatures for the local *A. parthenogenetica* strain (Bargozzi and Trotta, pers. commun., 1980; Vanhaecke et al., 1984). Other examples are N. African *Artemia* populations of local commercial solar saltworks, which used to inhabit highly seasonal biotopes that filled up during winter precipitation periods and dried up during the summer. Originally adapted to maximize population growth at relatively low temperatures, they do not readily tolerate the high summer temperatures to which they are now exposed in the salinas. A critical aspect regarding *Artemia* introduction is the selection of the strain to be inoculated. An accidental introduction of *A. parthenogenetica* from P.R. China into the solar salt operation on Great Inagua, Bahamas, resulted in significant reductions in salt quality and output (Morton Salt Cie, pers. commun., 1983). However, production returned to normal after the introduction of *A. franciscana*, which had previously been shown to control algal blooms under the local climatic conditions (E. Haxby, pers. commun., 1984). Serious problems resulting in sub-optimal conditions for solar salt production may also arise when natural re-colonization of the salt ponds after the winter

season is retarded due to particular climatological conditions. This is the case in the solar saltworks of the Bohai Bay (P.R. China). These solar saltworks are fed by highly eutrophicated waters causing an excessive accumulation of organic matter detrimental to salt production (Davis, 1991). Despite the abundant availability of food under the form of unicellular algae, *Artemia* densities in these salt ponds remain very limited especially during spring and are unable to remove sufficient amounts of organic matter. Overwintering cysts to repopulate the biotope during spring only hatch in the low salinity ponds due to absence of rain during this period. As a result, rapid colonization of the entire saltwork is prevented, because the high salinity ponds become populated with *Artemia* only when brine together with animals flow from the low salinity ponds to the downstream ponds. Repopulation of the biotope is furthermore exacerbated by the limited productivity of the local parthenogenetic strain at the lower temperature regimes prevailing in the ponds during spring as well as the poor resistance of this strain to high salinity (Tackaert and Sorgeloos, 1991). A recent inoculation trial, using *Artemia franciscana* from San Francisco Bay, USA, a strain selected for its high productivity at relatively low temperatures and good resistance to high salinities (Vanhaecke and Sorgeloos, 1988), in a local experimental saltworks largely out-competed the parthenogenetic strain confirming its better suitability for the Chinese saltworks. Although not yet scientifically verified, better salt quality and higher yields of *Artemia* biomass were also reported in the *Artemia franciscana*-inoculated salt ponds.

A new *Artemia* should be introduced only when one can be reasonably sure of its success, and certainly not before enough viable cyst material of the locally occurring strain has been collected to safeguard the conservation of this *Artemia* genepool. In accordance with a resolution adopted at the Second International *Artemia* Symposium, "...all possible measures (should) be taken to ensure that the genetic resources of natural *Artemia* populations are conserved". Such measures include the establishment of gene banks (cysts), close monitoring of inoculation policies and, where possible, the use of indigenous *Artemia* for inoculating *Artemia*-free ponds (Beardmore, 1987). Selection of the inoculated strain should be based on the available data on temperature and salinity tolerances (Vanhaecke et al., 1984; Vanhaecke and Sorgeloos, 1988), growth and production, reproductive characteristics, etc. Whenever possible, culture tests with various *Artemia* strains should be performed in simulated conditions, using the untreated waters of the habitat as culture medium. Competition between parthenogenetic and bisexual strains might favour the first when dealing with European bisexuals (*A. tunisiana*), although co-existence has been reported (Amat, 1983) with dominance of the parthenogenetic strain in the summer months. On the other hand we can confirm that *A. franciscana* strains always outcompete any other *Artemia* strain (Browne, 1980). Strain selection might also be restricted by the intended application of the produced *Artemia* in local aquaculture, e.g. an *Artemia* strain producing small cysts might be selected for use in sea-bass farming. Such introductions generally result in the permanent establishment of an *Artemia* population; introduction of an unsuitable strain cannot be readily rectified. Furthermore, adaptation of a newly inoculated strain may result in phenotypical and genotypical variations in the pre-existing stocks, eventually yielding a new *Artemia* genotype (Vanhaecke and Sorgeloos, 1988).

CONCLUSIONS

Now that it has been shown that salt making and *Artemia* production go hand in hand, one can envisage attractive joint ventures for shrimp and fish aquaculture operations to integrate with solar saltworks in some of the many thousands of hectares of salinas in the tropical–subtropical areas, often in climates that favour crustacean or fish farming. Furthermore, it can lead to an extra source of income for families in many developing countries (Sahavacharin, 1981).

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REFERENCES

Amat, T., 1983. Zygogenetic and parthenogenetic *Artemia* in Cadiz sea-side salterns. Mar. Ecol. Prog. Ser., 13(2–3): 291–293.

Beardmore, J.A., 1987. Concluding remarks. In: P. Sorgeloos, D.A. Bengtson, W. Decleir and E. Jaspers (Editors), *Artemia* Research and Its Applications. Vol. 1. Universa Press, Wetteren, Belgium, pp. 345–346.

Browne, R.A., 1980. Competition experiments between parthenogenetic and sexual strains of the brine shrimp, *Artemia salina*. Ecology, 61(3): 471–474.

Camara, M.R. and De Castro, E.V., 1983. *Artemia salina* L. (Anostraca): Uma opcao para aquicultura do Nordeste do Brasil. Revta Bras. Zool., S. Paulo, 1(3): 145–147.

Camara, M.R. and De Medeiros Rocha, R., 1987. *Artemia* culture in Brasil: an overview. In: P. Sorgeloos, D.A. Bengtson, W. Decleir and E. Jaspers (Editors), *Artemia* Research and Its Applications. Vol. 3. Universa Press, Wetteren, Belgium, pp. 195–199.

Davis, J.S., 1978. Biological communities of a nutrient enriched salina. Aquatic Botany, 4: 23–42.

Davis, J.S., 1980. Experiences with *Artemia* at solar saltworks. In: G. Persoone, P. Sorgeloos, O. Roels and E. Jaspers (Editors), The Brine Shrimp *Artemia*. Vol. 3. Ecology, Culturing, Use in Aquaculture. Universa Press, Wetteren, Belgium, pp. 51–55.

Davis, J.S., 1991. Biological management for the nutrient-rich Chinese solar saltworks. In: L. Cheng (Editor), Proceedings of International Symposium on Biotechnology of Saltponds, Salt Research Institute, Tanggu, Tianjin, PR China, 128–132 pp.

Geddes, M.C., 1980. The brine shrimp *Artemia* and *Parartemia* in Australia. In: G. Persoone, P. Sorgeloos, O. Roels and E. Jaspers (Editors). The Brine Shrimp *Artemia*. Vol. 3. Ecology, Culturing, Use in Aquaculture. Universa Press, Wetteren, Belgium, pp. 57–65.

Geddes, M.C., 1981. The brine shrimps *Artemia* and *Parartemia*. Comparative physiology and distribution in Australia. Hydrobiologia, 81: 169–222.

Geddes, M.C. and Williams, W.D., 1987. Comments on *Artemia* introductions and the need for conservation. In: P. Sorgeloos, D.A. Bengtson, W. Decleir and E. Jaspers (Editors). *Artemia* Research and Its Applications. Vol. 3. Universa Press, Wetteren, Belgium, pp. 19–26.

Haxby, R.E. and Tackaert W., 1987. Workshop report: Role of *Artemia* in solar salt operations. In: P. Sorgeloos, D.A. Bengtson, W. Decleir and E. Jaspers (Editors). *Artemia* Research and Its Applications. Vol. 3. Universa Press, Wetteren, Belgium, pp. 291–293

Jones, A.G., Ewing, C.M. and Melvin, M.V., 1981. Biotechnology of solar saltfields. Hydrobiologia, 82: 391–406.

Léger, P.H., Bengtson, D.A., Simpson, K.L. and Sorgeloos, P., 1986. The use and nutritional value of *Artemia* as a food source. Oceanogr. Mar. Biol. Ann. Rev., 24: 521–623.

Léger, P.H., Bengtson, D.A., Sorgeloos, P., Simpson, K.L. and Beck, A.D., 1987a. The nutritional value of *Artemia*, a review. In: P. Sorgeloos, D.A. Bengtson, W. Decleir and E. Jaspers (Editors). *Artemia* Research and Its Applications. Vol. 3. Universa Press, Wetteren, Belgium, pp. 357–372.

Persoone, G. and Sorgeloos, P., 1980. General aspects of the ecology and biogeography of *Artemia*. In: G. Persoone, P. Sorgeloos, O. Roels, and E. Jaspers (Editors). The Brine Shrimp *Artemia*. Vol. 3. Ecology, culturing, use in aquaculture. Universa Press, Wetteren, Belgium, pp. 3–24.

Sahavacharin, S., 1981. Ways to convert salt farm to *Artemia* farm (in Thai, with English abstract). Thai Fisheries Gazette, 34(5): 467–480.

Sorgeloos, P., 1983. Brine shrimp *Artemia* in coastal saltworks: inexpensive source of food for vertically integrated aquaculture. Aquaculture Magazine, 9: 25–27.

Sorgeloos, P., Lavens, P., Léger, Ph., Tackaert, W. and Versichele, D., 1986. Manual for the Culture and Use of Brine Shrimp *Artemia* in Aquaculture. *Artemia* Reference Center, State University of Ghent, Belgium, 319pp.

Tackaert, W. and Sorgeloos, P., 1991. Biological management to improve *Artemia* and salt productions at Tang Gu Saltworks in the P.R. China In: L. Cheng (Editor), Proceedings of International Symposium on Biotechnology of Saltponds, Salt Research Institute, Tanggu, Tianjin, PR China, pp. 78–83.

Tackaert, W. and Sorgeloos, P., 1992. Salt, *Artemia* and shrimp. Integrated production in the Peoples' Republic of China: The Tang Gu Saltworks. World Aquaculture, in press.

Vanhaecke, P., Lavens, P. and Sorgeloos, P., 1983. International Study on *Artemia*. XVII. Energy consumption in cysts and early larval stages of various geographical strains of *Artemia*. Annls. Soc. r. zool. Belg., 113(2): 155–164.

Vanhaecke, P., Siddal, S.E. and Sorgeloos, P., 1984. International Study on *Artemia*. XXXII. Combined effects of temperature and salinity on the survival of *Artemia* of various geographical origin. J. Exp. Mar. Biol. Ecol., 80(3): 259–275.

Vanhaecke, P. and Sorgeloos, P., 1988. International Study on *Artemia*. The effect of temperature on cyst hatching, larval survival and biomass production of different geographical strains of *Artemia*. Submitted for publication.

Vanhaecke, P., Tackaert, W. and Sorgeloos, P., 1987. The biography of *Artemia*: an updated review. In: P. Sorgeloos, D.A. Bengtson, W. Decleir and E. Jaspers (Editors), *Artemia* Research and Its Applications. Vol. 1. Universa Press, Wetteren, Belgium, pp. 129–159.

Wear, R.G. and Haslett, S.J., 1987a. Studies on the biology and ecology of *Artemia* from Lake Grassmere, New Zealand. In: P. Sorgeloos, D.A. Bengtson, W. Decleir and E. Jaspers (Editors), *Artemia* Research and Its Applications. Vol. 3. Universa Press, Wetteren, Belgium, pp. 101–126.

Wear, R.G. and Haslett, S.J., 1987b. A minimal strategy for assessing *Artemia* biomass harvestable from production salinas. In: P. Sorgeloos, D.A. Bengtson, W. Decleir and E. Jaspers (Editors), *Artemia* Research and Its Applications. Vol. 3. Universa Press, Wetteren, Belgium, pp. 217–220.